

NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division

December 18, 2019

Sound Spectrum Study

Group Chairman's Factual Report
By Sean Payne

1. EVENT SUMMARY

Location: Baytown, Texas
Date: February 23, 2019
Aircraft: Boeing 767-375BCF, Registration N1217A
Operator: Atlas Air Cargo, Flight 3591
NTSB Number: DCA19MA086

On February 23, 2019, at 1239 central standard time (CST), Atlas Air flight 3591, a Boeing 767-375BCF, N1217A, entered a rapid descent from 6,000 feet and impacted a marshy bay area about 40 miles southeast of George Bush Intercontinental Airport (KIAH), Houston, Texas. The airplane was destroyed and highly fragmented. The two pilots and one nonrevenue jumpseat pilot were fatally injured. The domestic cargo flight was operating under Title 14 *Code of Federal Regulations* Part 121 from Miami International Airport (KMIA), Miami, Florida to KIAH

A solid-state cockpit voice recorder (CVR) was sent to the National Transportation Safety Board (NTSB) Vehicle Recorder Division for evaluation.

2. GROUP

A group was convened on September 16th, 2019, at the NTSB's Vehicle Recorder Division laboratory in Washington, D.C. The group consisted of the following individuals:

Chairman:	Sean Payne Sr. Mechanical Engineer/Investigator NTSB
Member:	Charles Cates Sr. Mechanical Engineer/Investigator NTSB
Member:	Bernard Sklanka Associate Technical Fellow – Sound Engineering Lab Boeing

Member: Alex Kremer
Lead Acoustic Engineer – ANP Laboratory
Boeing

3. DETAILS OF INVESTIGATION

The NTSB Vehicle Recorder Division received the following CVR:

Recorder Manufacturer/Model: **Honeywell 6022**
Recorder Serial Number: **61829**

3.1 Audio Recording Description

The CVR's downloaded audio information was not pristine. Specifically, on both the two-hour portion and the 30-minute portion of the recovered audio files, crew hot-mic information was mixed with VHF radio traffic. This is not uncommon, as squelch and volume settings can affect these conditions. Any time there was a VHF transmission on the same frequency as the accident aircraft, crew hot-mic information was obscured. In general, the VHF information was recorded at a higher decibel level which made crew hot-mic information more difficult to discern. Only during times in which no VHF radio transmissions were present, was the crew audio information from the hot channels was intelligible.

For the two-hour CAM portion, the first 1 hour 43 minutes and 12.6 seconds of the recording was characterized as "fair."¹ At 1 hour 43 minutes and 12.6 seconds into the recording (12:21:19 CST), the quality of the CAM channel degraded. The CAM channel dropped in recorded decibel level and remained at this level for the remainder of the recording. At this time, CAM audio information was characterized as "poor." The time for when this situation occurred is specifically noted in the transcript.

For the 2 hour mixed hot mic track, the quality was rated as poor due to the mix of recorded VHF communications which interfered with the quality of crew communications via hot mic on this channel.

For the 30-minute portion of the recording, each channel's audio quality is indicated in Table 1.

For the two-hour portion of the recording, each channel's audio quality is indicated in Table 2.

¹ See attached CVR Quality Rating Scale.

Table 1: Audio Quality for 30 minute portion.

Channel Number	Content/Source	Quality	Duration
1	Jumpseat Position (un-used)	N/A	30m33s
2	First Officer	Fair	30m33s
3	Captain	Fair	30m33s

Table 2: Audio Quality for two-hour portion

Channel Number	Content/Source	Quality	Duration
1	Captain, First Officer and Jumpseat	Poor	2h05m16s
2	Cockpit Area Microphone (CAM)	Poor	2h00m56s

3.2 Timing and Correlation

Timing on the transcript was established by correlating the CVR events to common events on the flight data recorder (FDR). Specifically, the last three radio transmissions that the aircraft made were correlated to the radio transmit microphone key parameter from the FDR. Each of the three radio transmissions acted as an anchor point for a linear interpolation between the remaining CVR events. Once a correlation between the three recorders was established, a reference to local time was determined using additional timing information from the FDR. The resolution of the recorded mic keys on the FDR was 1 Hz.

3.3 Sound Spectrum Study

A sound spectrum study was undertaken to attempt to determine the following:

- Examine and potentially characterize the area of audio at 12:21:18.9 CST when the audio quality degraded for the remainder of the recording
- Identify the source of a clicking sound at 12:38:31.1 CST
- Identify and characterize the sources of tones heard during the accident portion of the recording

Signal Level Change at 12:21:18.9 CST

Audio 17 seconds prior to the noise level dropout and audio 17 seconds following the noise level dropout was analyzed using two software tools, IzoTope RX4 and Head Acoustics Sound Engineering Project. Figure 1 shows the region of audio analyzed during this exercise as displayed in IzoTope RX4.

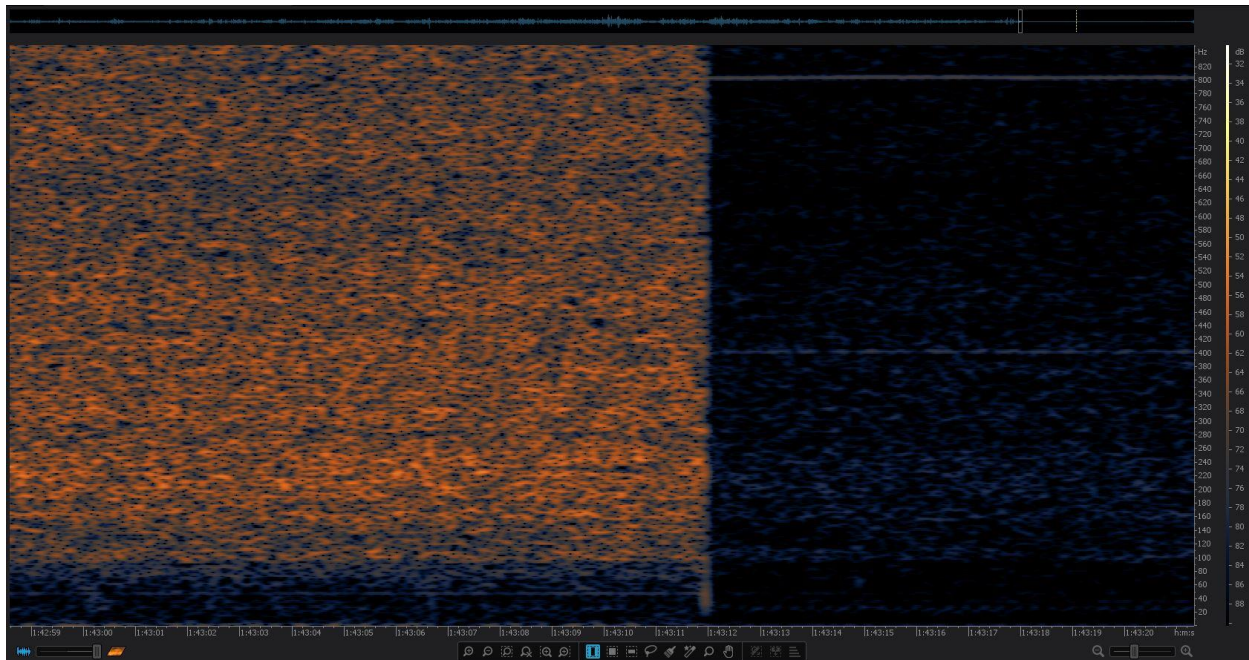


Figure 1. Region of interest examined in IzoTope RX4.

In figure 1, the signal to noise ratio has been adjusted to more clearly delineate characteristics of the recording. The adjustment clearly shows a 400 Hz power tone and associated harmonics at 800 Hz, 1600 Hz and repeating.

Next, the 17 seconds prior to the noise level change and the 17 seconds post the noise level change were processed individually, using a Fast-Fourier Transform (FFT) in Head Acoustics Sound Engineering Project. Figure 2 shows the results of this exercise. Channel 1 (green signal) was defined as an input of the 17 seconds prior to the audio change. Channel 2 (red signal) was defined as an input of the 17 seconds post the audio change. The level between the two signals had to be offset by 24 dB in order for the two signal's characteristics to match, meaning that overall level change was 24 dB.

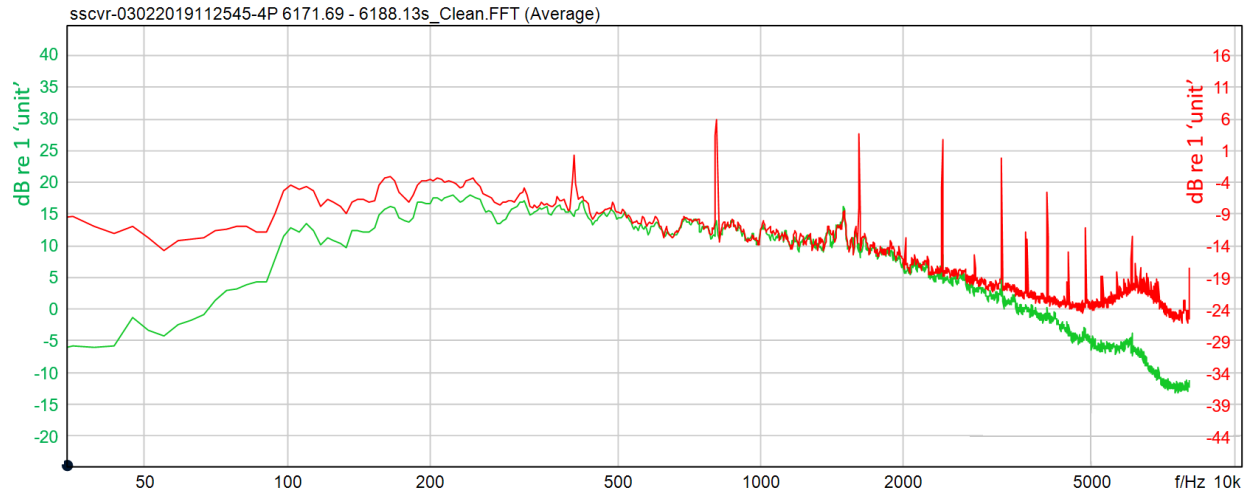


Figure 2. A FFT of 17 seconds prior to the audio level change (Channel 1 in green) and a FFT of 17 seconds post the audio level change (Channel 2 in red). The curves were plotted together to show that the background level is the same within the range of 500 Hz to 2000 Hz. However, there is a 24 dB shift between the curves. The red curve shows noise floor influence below 500 Hz and above 2000 Hz.

In figure 2, channel 2 is shown (red) as having frequency values at 400 Hz, 800 Hz, 1600 Hz and repeating at higher frequency levels. Channel 1 (green) shows a “cleaner” signal with limited frequency values than those observed in channel 2.

Additionally, a root mean square (RMS) value was measured for a time interval 10 seconds before and a time interval 10 seconds after the signal change. The RMS value was 22.2 dB higher prior to the signal change than the RMS measured after the signal change.

As a result of this change in decibel level, dynamic range is lost, resulting in the loss of some audio data.

Characteristics of a clicking sound at 12:38:31.1

[Sound of Click.]

A clicking sound was detected at 12:38:31.1 CST, “[Sound of Click.]” The time alignment of this clicking sound matched FDR data of that of go around mode activation² registered to the FDR. The characteristics of the clicking sound was examined using Head Acoustics Sound Engineering Project.

Figure 3 is a screen capture of sound spectrum information around the time of the clicking noise. A circle annotates an area of sound energy believed to be associated with the

² Refer to Flight Data Recorder Specialist’s Factual Report which is available in the public docket for this accident. Data recorded to the FDR related to VHF microphone keying was used to correlate FDR data to CVR audio. VHF keying was sampled once every second. A series of three VHF keys were used to correlate timing information.

clicking noise. Using digital filtering, it is possible with the human ear to hear the clicking noise.

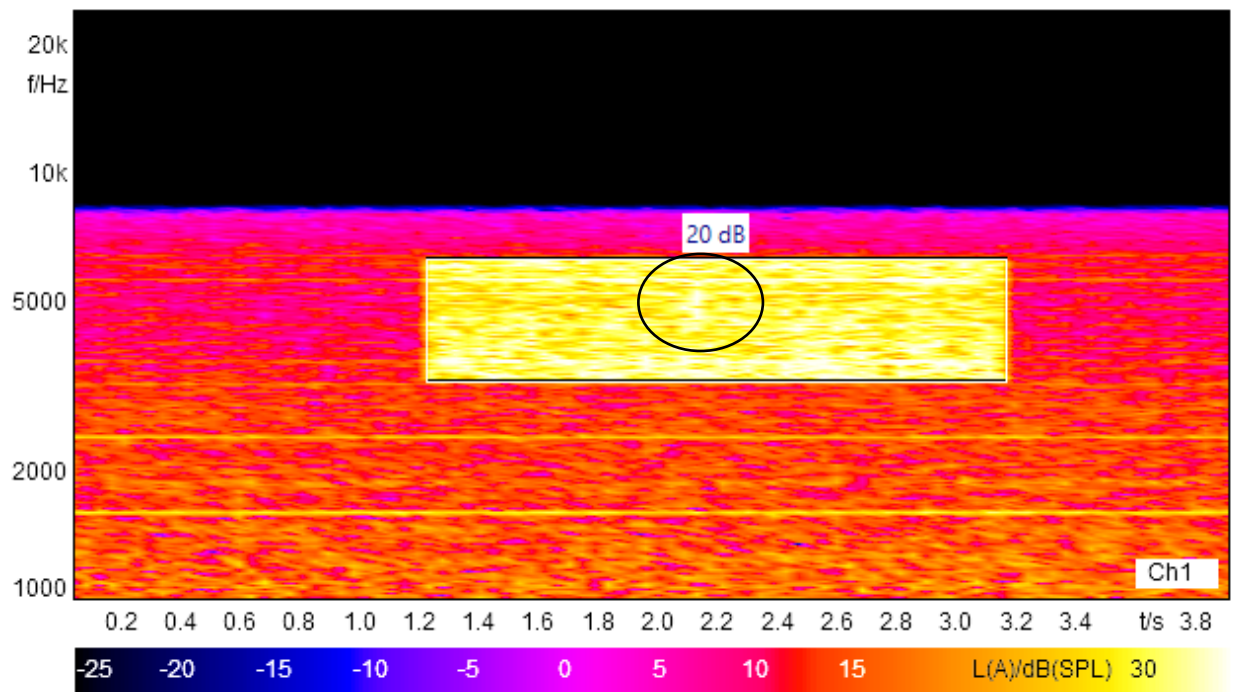


Figure 3. Sound energy potentially associated with the clicking noise detected at 12:38:31.1 CST.

Figure 4 is a screen capture of sound energy isolated around a frequency of 5000 Hz for a duration of approximately 2 seconds. Using this method, all sound information outside the region around 5000 Hz is removed and only sound information within the selected region is audible. With these settings, the clicking sound is audible to the human ear. A circle denotes the same portion of sound energy as shown in figure 3, which was associated with the clicking noise.

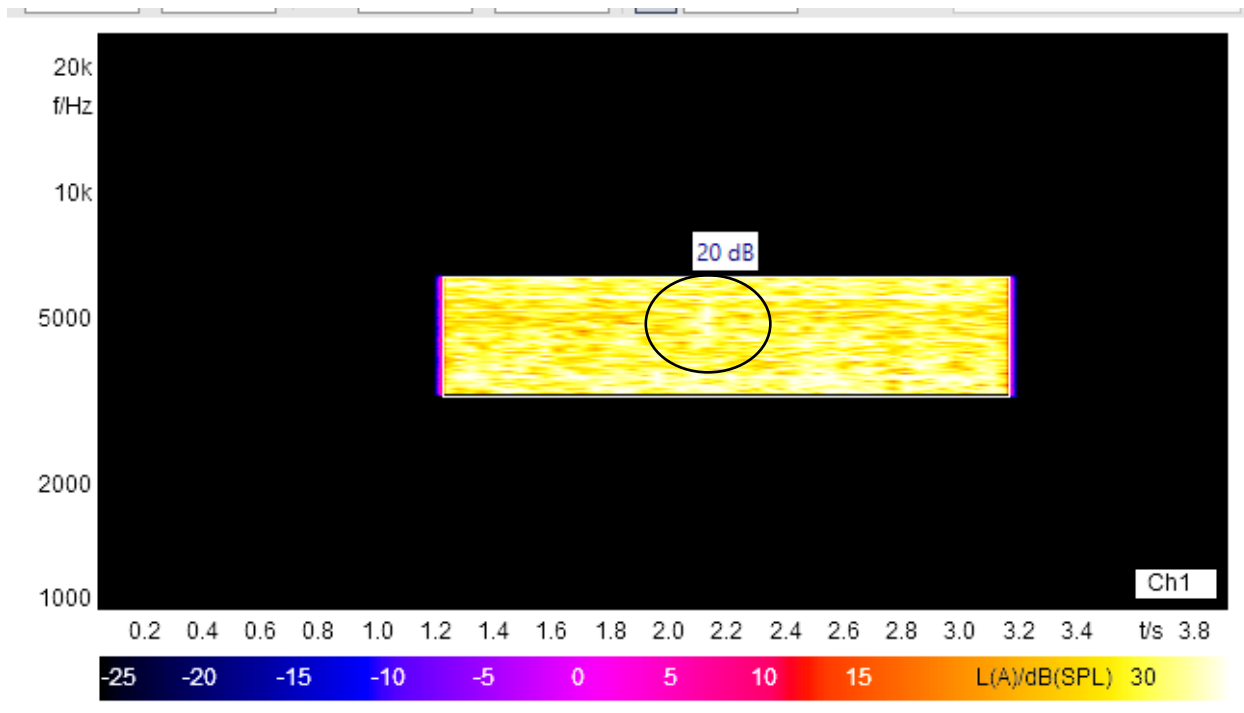


Figure 4. Sound energy isolated at an approximate 5000 Hz correlating to the clicking noise at 12:38:31.1 CST. The clicking sound was audible with all other sound energy information removed.

Figure 5 is a screen capture of sound spectrum information associated with an exemplar recording of a go around button (GA) activation of a 767 freighter while on the ground. The exemplar information revealed the sound associated with the exemplar GA button depress is two distinct sounds which can be described as a double action click. One sound is associated with the depression of the switch and the second sound is associated with the release of the switch. The sound of release of the GA switch has a higher sound energy content. These noises carry through a frequency range of approximately 1kHz to 10 kHz, however, these sounds have an elevated characteristic of sound energy around 5000 Hz. Circles placed on figure 5 point to a regions of elevated sound energy at 5000 Hz associated with an exemplar GA button depress and release cycle.

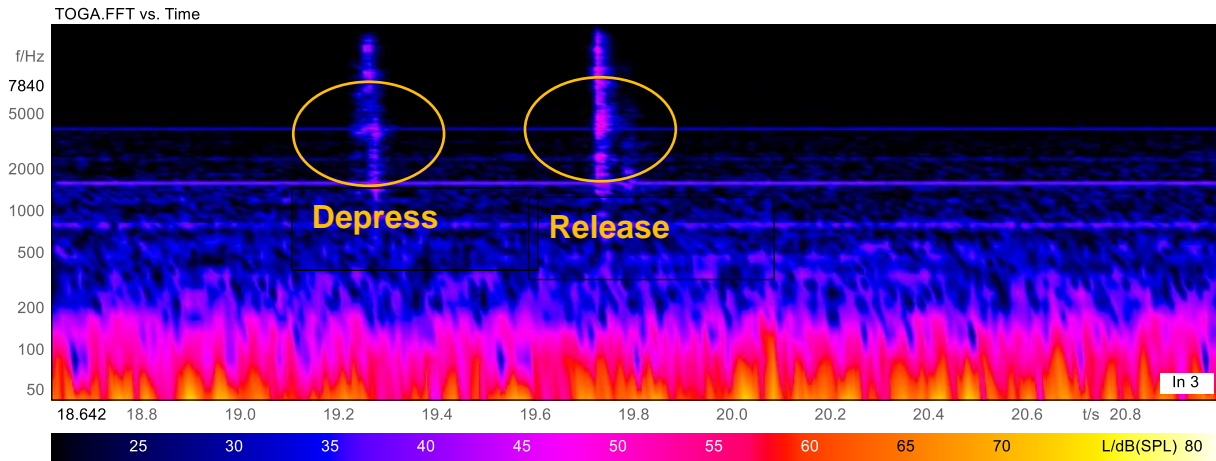


Figure 5. TOGA actuation on a 767 freighter on ground. Microphone is a B&K 4192 held at CAM panel location.

The clicking sound that occurred at 12:38:31.1 CST occurred in the region of audio after the CAM audio had been degraded. As shown above in the report, this region of audio contains 24 dB less sound energy than was available in the beginning of the recording. As described in the section above, this 24 dB is a loss of overall sound information.

Next, the exemplar recording of the GA button activation was mixed with the sound of 767 freighter in a descent from 5,000 feet. Additionally, this exemplar sound mix was then filtered to match the response characteristics of a Cockpit Area Mic (CAM). Then this mix was down sampled to 16,384 Hz in order to represent the accident aircraft's CVR CAM channel characteristics. Additionally, the sound level was also degraded further to replicate the performance of the CAM at the time clicking sounds was recorded. Figure 6 is a screen capture of the sound spectrum analysis for the conditions described above. This simulates the exemplar GA button activation recording in simulated flight conditions with the audio degraded to function similar to that of the CAM on the accident flight. Similar to the accident recording, only one area of sound energy is present (around 5,000 Hz) in the sound spectrum.

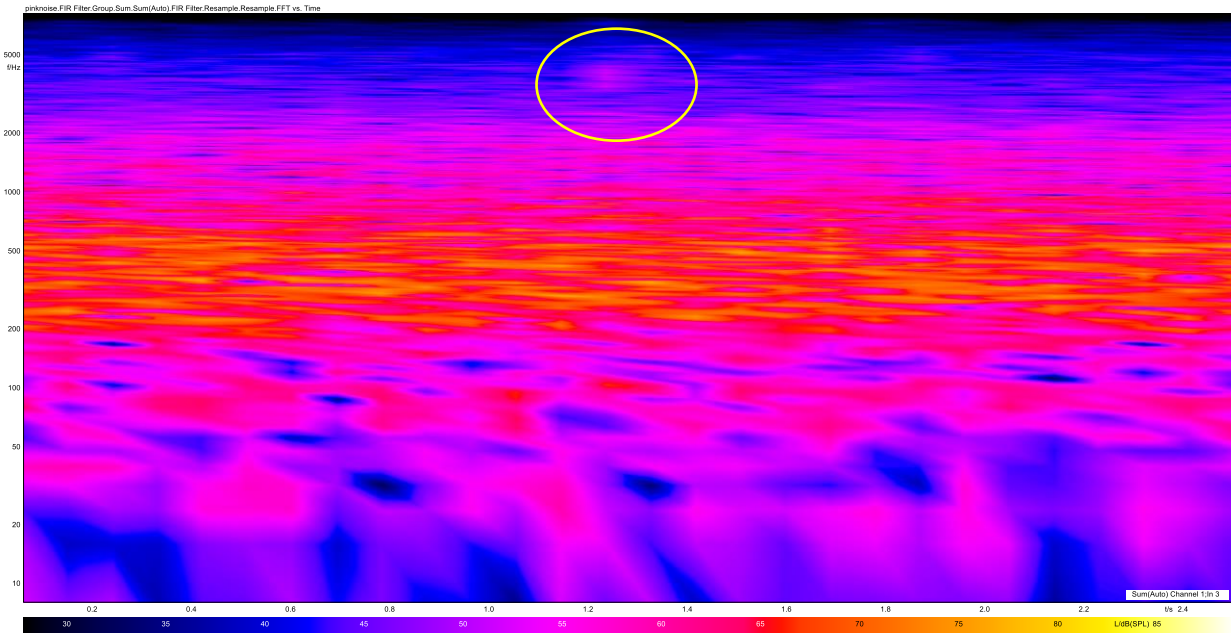


Figure 6. An exemplar recording of a GA button activation on a 767, mixed with the sounds of an exemplar 767 aircraft descending from 5,000 feet. The energy of the GA clicking sound is circled in the above plot. The energy was around 5,000 Hz.

The clicking sound at 12:38:31.1 CST shares a similar characteristic of an exemplar GA button activation (elevated sound energy at 5000 Hz). The dual clicking nature of the exemplar recording was not detected in this region, and may not have been possible to detect the dual nature of the exemplar noise for the recording to capture due to the aircraft being in flight with an additional 24 dB decrease in sound energy. Since the release portion of the GA click contains more sound energy, the clicking noise on the accident recording could potentially be associated with the release of the GA button.

In summary, the clicking noise shares some characteristics of the exemplar GA button activation, specifically the release portion of an exemplar GA button activation, however, it cannot be conclusively determined if it is the same sound due to the degraded quality of the CAM channel recording at the time of the sound detection (12:38:31.1 CST).

Sources of Tones in the Final Portion of the Recording

Tones and beeps that appear in the final portion of the recording were examined in order to correlate these sounds with aircraft warning systems. During the transcription process, the group members did not assign the beeps and tones that were present on the audio recording to specific aircraft related tones. The following timing information and sound descriptions are provided from the CVR transcript.

12:38:40.3 CST

“Sound of four Beeps within a duration of .75 seconds at a frequency of 1200 Hz”

Figure 7 is an exemplar recording of the “owl” beeper aural warning. According to Boeing’s Flight Crew Operations Manual for this aircraft (FCOM) which covers system descriptions for aural alerts, *“Beeper is used for all system alert caution messages. The beeper consists of a tone that sounds four times in a second. The beeper automatically silences after one series of four beeps.”* The exemplar recording of the beeper shows the level at 1,000 Hz.

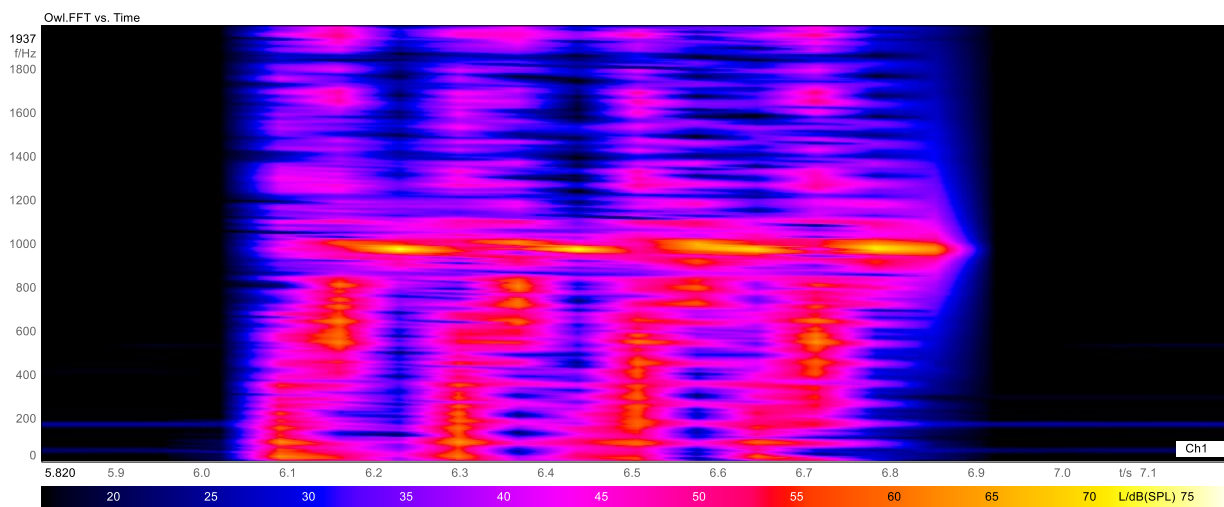


Figure 7. An exemplar recording of the “Owl” beeper aural warning.

Figure 8 is the “four beeping” sound from the accident recording at 12:38:40.3 CST. During the accident flight, a four beeping sound was registered at approximately 1,200 Hz.

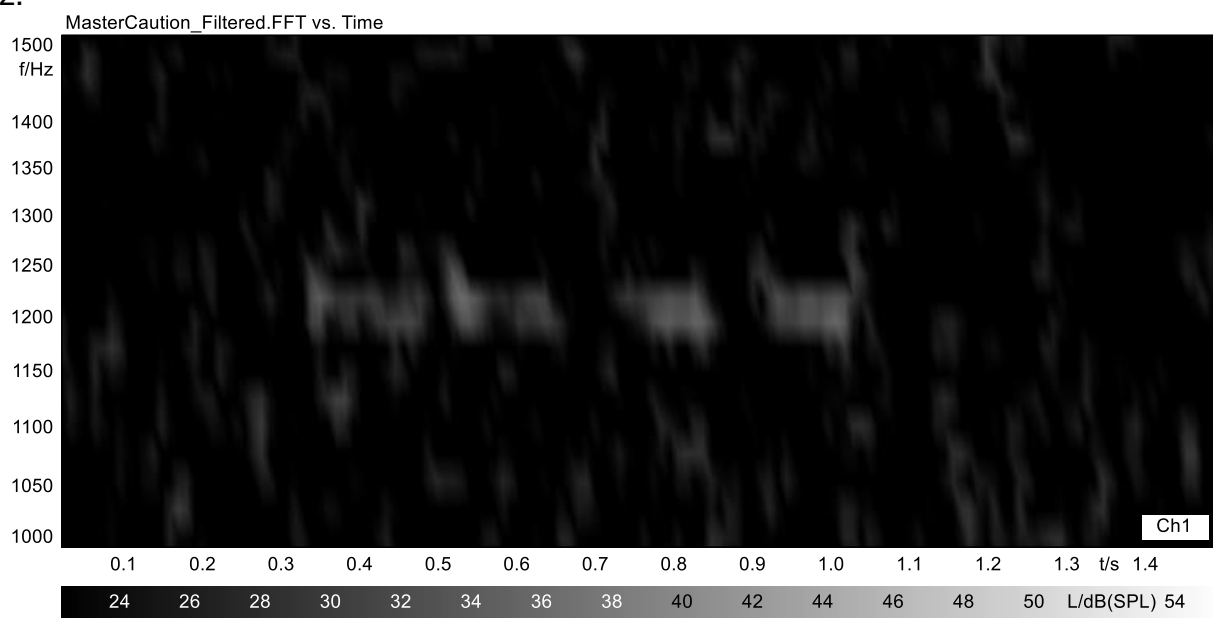


Figure 8. Four beeping sound from the accident recording at 12:38:40.3 CST.

The four tones are consistent with the ‘owl’ beeper aural warning. According to Boeing, this warning is “four repetitive tone bursts each increasing in frequency through the first portion of the burst after which, the frequency shall remain constant until the end of the burst. The burst shall start at approximately 20 Hz and sweep to approximately 1000 Hz over the first quarter of the burst and shall remain at 1000 Hz for the remainder of the burst period.” The owl does not call out a specific fixed value, as it’s ‘approximately 1000 Hz’. According to Boeing, 20% tolerance is an acceptable probability for this system. The frequency is inversely proportional to the voltage applied to the timer; therefore, the voltage timer impacts the owl ending frequency.

12:38:56.3

“Sound of 1000 Hz series of beeps with approximately .25 second spacing begin. Group could not determine if audible sound lasted until end of recording.”

Figure 9 is an exemplar recording of the “Siren.” According to Boeing’s FCOM for this aircraft, “Siren – Used to annunciate cabin altitude, configuration, autopilot disconnect and overspeed warning alerts. The siren consists of alternating high and low tones.”

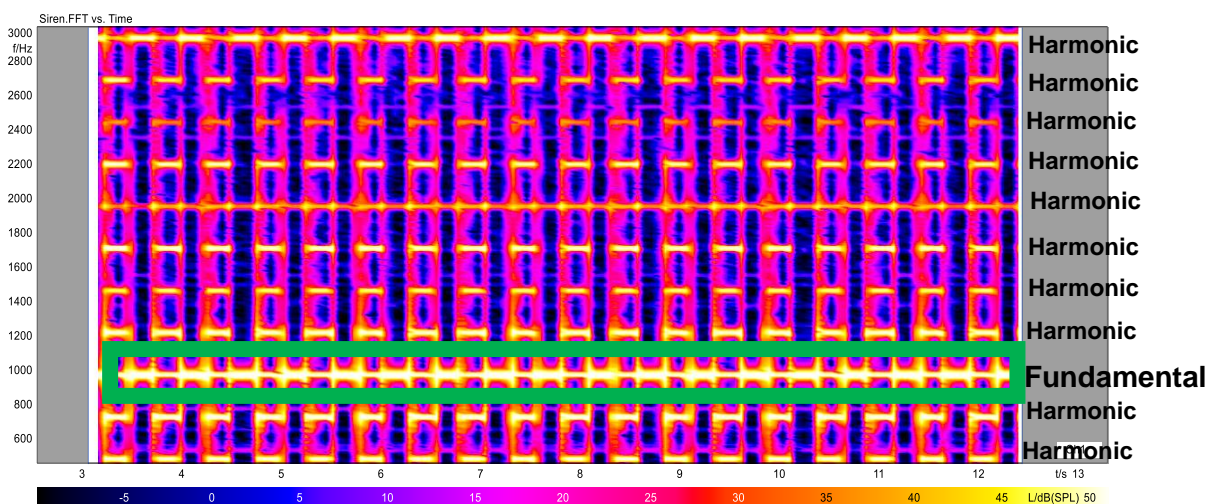


Figure 9. An sound spectrum of an exemplar recording of the “Siren” and its harmonics. The fundamental frequency is highlighted at 1,000 within the green box.

Starting at 12:38:56.3 CST, a 1,000 Hz frequency is detected in the spectrogram from the accident recording. No obvious harmonics were detected. The spectrogram for this sound has a slight alternating high and low frequency characteristics. Figure 10 is the spectrogram of the accident recording at this time.

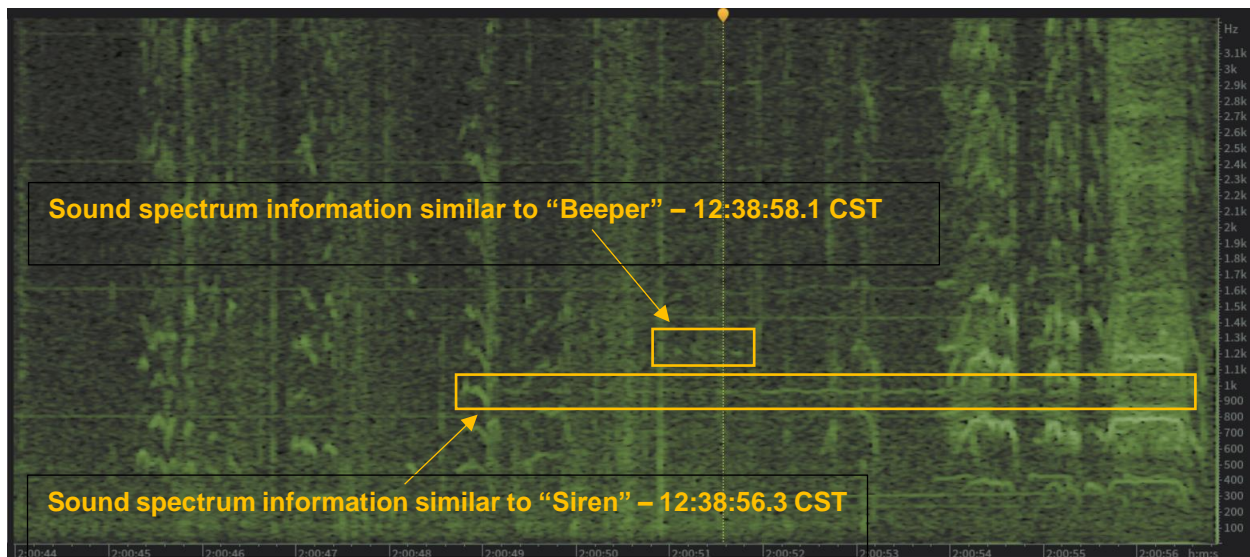


Figure 10. A sound spectrogram of the end of the recording which contains a component similar to the aircraft’s “Siren.” The four beeping sound (beeper) at 12:38:58.1 CST is also noted.

12:38:58.1

“Sound of quick series of four beeps at 1200 Hz”

The same four beeping sound detected at 12:38:40.3 CST was detected again at 12:38:58.1 CST. The characteristics of this beeping sound are the same as described in that section. This sound is likely to be the aircraft’s “beeper.” This area is shown in figure 11.

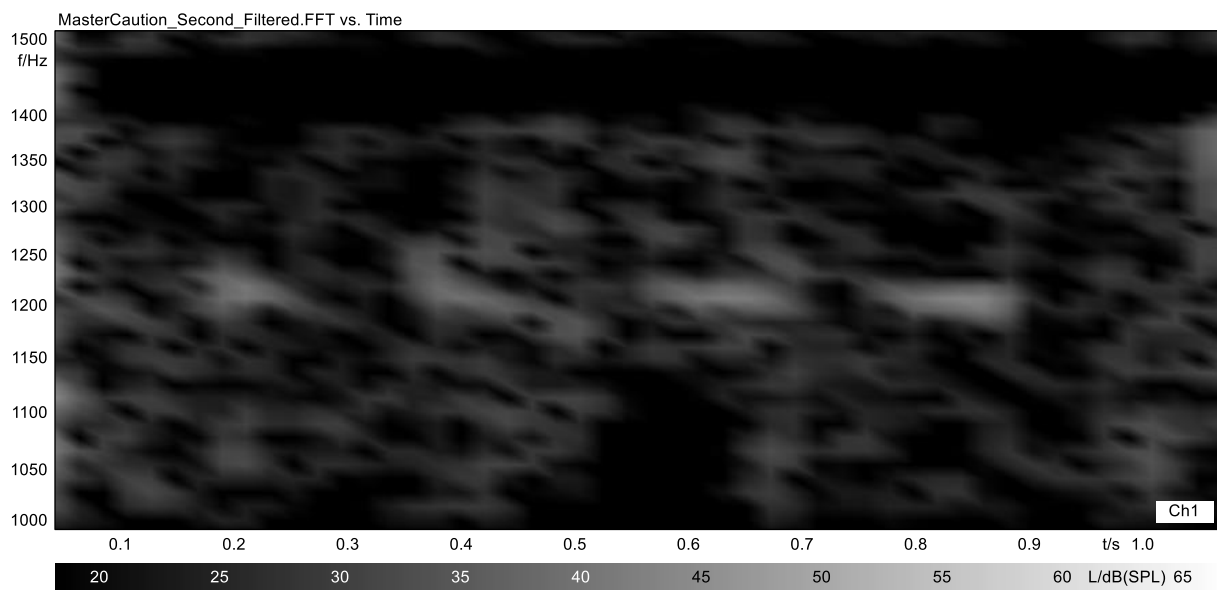


Figure 11. “Sound of quick series of four beeps at 1200 Hz” at 12:38:58.1 CST

12:38:58.9

“Sound of longer duration pulse tone about 1000 Hz, similar to Siren. Group could not determine if audible sounds lasted until end of recording.”

The group that transcribed the CVR then described a sound “similar to Siren” at 12:38:58.9 CST. When referencing figure 10, the sound spectrum shows a sound profile that carried through from 12:38:56.3 CST. When reviewing the information shown in figure 10, it is likely the beeper began at 12:38:56.3 CST. It is unclear if the beeper ceased prior to the termination of the recording as other sound information is obscuring the signal in the final moments of the recording.